PUBLIC ROADS

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BUREAU OF PUBLIC ROADS

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KEEP THE MIXER GOING BY ANTICIPATING PREVENTABLE DELAYS

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TIME LOSSES IN CONCRETE ROAD CONSTRUCTION

Reported by ANDREW P. ANDERSON, Highway Engineer, United States Bureau of Public Roads

ALL contractors and engineers familiar with concrete road construction are fully aware that, at best, the actual annual production of any outfit is always far below the potential productive capacity of the mixer. This failure to approach the production possibility of the controlling equipment is due to a large number of reasons which may be grouped under two main classes: (1) Slow or inefficient operation when actually at work; and (2) failure to operate at all for more or less extended intervals during the working season. The more general term of "time losses" is usually applied to this second class.

The first class—slow or inefficient operation—its causes and effects, as well as means and methods for securing more efficient production, has been fully discussed in previous studies reported in this magazine [1] and will therefore be referred to only incidentally in this article.

During the construction seasons of 1925 and 1926 the Bureau of Public Roads in connection with its studies of production engineering made careful records on a large number of active concrete pavement jobs of the time losses and delays which served to hold up production entirely or to reduce it below its normal rate. These studies are still being continued, but the data now cover projects scattered over such a wide region as to form what may be considered a somewhat representative indication of the average conditions under which a substantial portion of our total annual concrete road construction is performed.

If the data accumulated for the past two years are representative of average conditions, of which there would seem to be little doubt, the average concrete paver operating on State road construction does not reach an average of 1,000 hours of actual mixer operation per season, even when supplied with ample work under contract. Some, where contracts are short or conditions otherwise unfavorable, do not exceed 500 hours of actual mixer operation. For the region covered by these studies, which extends from and includes Pennsylvania in the East to Nebraska and Oklahoma in the West, and from Michigan in the North to Texas and Florida in the South, 2,000 hours may be considered as the available working time per season in the more favored sections, except for rather limited areas in the extreme South, and about 1,500 hours as the available time in the less favored areas. This is the length of the average working season under present prevailing practice, exclusive of Sundays and holidays. This report will therefore review the causes which so greatly reduce the actual productive operating time in concrete road construction below that which is apparently available, the effect of such time losses, and what suggestions such data as are now available contain as to how these time losses may be reduced.

INITIAL AND PREPARATORY LOSSES

The first kind of time losses encountered by the concrete road contractor are those involved in securing the contract and in preparation incidental to getting onto the job. These are elusive factors about which sufficient definite data are as yet unavailable. The rather general practice of letting contracts in the spring instead of in the fall or early winter has a tendency to increase these losses. If the contractor fails to secure a contract at the first spring letting a considerable portion of the season may be lost before another letting is held; or where, as is so often the case, when the earthwork and structures are let as separate contracts these contractors may fail to push their work with sufficient vigor to permit paving operations to begin as early in the spring as would otherwise be possible or to carry them on consistently during the season. The actual extent of these losses, however, is largely unknown except as they serve to reduce the length of the average construction season.

The present studies have, in general, covered only the more tangible losses occurring after the arrival of the contractor on the job in the spring until work is discontinued in the fall. Furthermore, in these studies only definite cessations of mixer operation, each of 15 minutes or more in duration, have been classed as time losses. All of the unnumerable stops of less than 15 minutes each have been considered rather as the natural manifestations of slow or inefficient operation than as due to the more or less accidental or fortuitous causes or circumstances to which we are generally accustomed to ascribe time losses. For a full discussion of such minor and accumulative time losses as are due to inefficient management, the reader is referred to the previously mentioned series of articles entitled "Efficiency in Concrete Road Construction."

On this basis it appears from the data accumulated that what might be termed the average concrete road construction outfit from the time it arrives on the job until it is closed down for the winter actually pours concrete during less than 53 per cent of the available working time within this period. Nearly one-half of the time the outfit is on the job and should be engaged in productive work is therefore lost for various reasons. Tables 1 and 2 show the general average distribution of these time losses for the past two working seasons. The first column of Table 1 shows the percentage of the total available working time lost on account of more important causes, while the second shows the percentage which each of these causes contributed to the total time losses. Table 2 shows the percentage of the total available working time lost on each of 32 projects on account of the more frequently occurring causes.

TABLE 1.—*Average time losses by the mixer in concrete paving construction*

Percentage of total working time	Percentage of total time loss	Cause
21.5	45.4	Rain and wet subgrade or wet road.
4.8	10.2	Moving, generally from one set-up to another.
4.3	9.0	Waiting for subgrade to be prepared.
4.1	8.6	Hauling equipment slow or inadequate.
3.5	7.4	All miscellaneous causes.
2.6	5.5	Mixer trouble and repairs to mixer.
3.0	6.3	No materials at yard or source of supply.
1.8	3.8	No water, pipe line and pump trouble.
1.1	2.3	Cold weather.
.5	1.1	Time limit on fills.
.2	.4	Waiting on finishers.
47.4	100.0	

[1] "Efficiency in Concrete Road Construction," PUBLIC ROADS, vol. 6, Nos. 9, 10, 11, 12; vol. 7, No. 1.

Table 2.—*Percentage of total available working time lost on account of various causes on several projects*

Project No.	State	Dates (inclusive)	Total time losses	Weather losses: Rain and wet subgrade	Weather losses: Cold weather	Moving	Subgrade not prepared	Hauling equipment	Lack of material	Mixer trouble and repairs	Water	Time limit on fills	Finishing	Loading plant	Miscellaneous
1	Texas	Mar. 24 to June 2	60.3	39.3		3.0	10.5	2.3	1.5	0.6	0.8				2.3
2	Oklahoma	Oct. 27 to Nov. 19	44.7	13.5	10.7	9.4	.8				6.0			2.5	1.8
3	Texas	Mar. 1 to Apr. 30	49.7	45.5			1.3		.9	.6	1.4				
4	Missouri	Apr. 7 to June 6	40.3	28.8		1.0	1.1	5.3		.9					3.2
5	do	May 2 to July 31	43.5	30.0		1.9	5.0	2.2		.3			0.7		3.4
6	do	May 27 to July 31	38.8	23.9		1.8	8.5	.8			1.3		1.0		1.5
7	do	July 10 to July 31	44.7	9.3				27.5		1.4			1.5	1.8	3.2
8	do	Apr. 22 to Sept. 18	29.8	21.6		6.2		.4							1.6
9	do	Aug. 1 to Aug. 25	36.0	25.6			5.8								4.6
10	do	Aug. 18 to Aug. 27	29.4	17.3		9.8				1.4					.9
11	Nebraska	Sept. 14 to Sept. 30	25.0	23.7											1.3
12	Missouri	Aug. 10 to Nov. 19	45.8	25.6	3.9	4.9	1.3			2.1	.9			7.1	
13	do	June 12 to Nov. 24	48.4	29.6	2.6	6.3	2.8	3.0		1.7	.4				2.0
14	do	Oct. 9 to Nov. 24	62.9	36.0			15.4	.8		.5	4.2				6.0
15	Illinois	Apr. 30 to Nov. 7	48.5	21.1	2.5	4.1	2.6	4.5	1.1	5.3	6.0				1.3
16	do	May 18 to Nov. 6	53.6	19.8	.2	12.8	2.0	8.7		5.2	.5				4.4
17	do	May 18 to Nov. 5	46.7	13.3	5.1	12.9	.8	10.4	.5	2.6	1.1				
18	Florida	Oct. 9 to Jan. 19	64.4	12.9	1.1		30.8	2.7			1.1	9.7			6.1
19	do	Apr. 25 to Jan. 28	44.8	17.6		6.3	1.9	1.1	8.6	5.5	1.3		.3		2.2
20	Mississippi	Oct. 24 to Dec. 7	57.9	23.0			11.4		7.7	3.0	3.1		.6	6.0	3.1
21	Texas	Apr. 16 to July 31	51.8	14.9		2.4	4.0	2.9	10.7	10.5	2.5			.5	3.4
22	do	June 15 to July 11	58.0	35.8		5.9	1.9	1.3	9.8	.4	.5				2.4
23	do	June 17 to Aug. 1	41.6	3.5			19.2	3.3		.2	.4			11.0	4.0
24	do	Aug. 9 to Aug. 21	64.1	26.1			24.6			1.3	.6				11.5
25	Missouri	May 24 to Sept. 25	55.8	29.6		7.5	3.6	.3		2.3	9.6		1.0	.1	1.8
26	Michigan	June 7 to Sept. 11	34.0	10.3		1.8	3.2	5.8	1.3	1.7	.1		.3	3.7	5.8
27	do	June 14 to Sept. 11	48.4	15.8			3.6	7.9	13.5	.5	.9			.2	6.0
28	do	June 21 to July 10	26.0	.3			8.0	1.9		.8	3.5		7.3		4.2
29	Missouri	June 14 to Sept. 4	55.0	24.7				20.4	2.4	3.6	1.5		.5		1.9
30	Oklahoma	June 14 to July 17	28.9	20.7			1.6		5.0						1.6
31	do	June 21 to July 31	35.0	16.8		8.9	1.3	.5	1.8	1.4	1.6		.1		2.6
32	do	Aug. 9 to Sept. 11	50.1	16.0		2.1	.4	.3	7.3	.4	6.0	13.1		3.7	.8
	Average		47.4	21.5	1.1	4.8	4.3	4.1	3.0	2.6	1.8	.5	.2	.6	2.9

The most striking item in these tables is the relatively large amount of time lost because of rain and wet subgrade. It is very difficult to determine just how the losses should be divided between actual rain and wet subgrade. Apparently, however, less than one-fifth of the total time losses here charged to the combined causes were due to the actual fall of rain during working hours. On one fairly typical job the total losses charged to rain and wet subgrade amounted to 385¾ hours, and of this total only 53 hours were due to actual rainfall during working hours. The detrimental effect of the rainfall on the subgrade or the road or track over which the hauling is done is therefore clearly the major factor in this class of time losses.

When so large a proportion of the so-called rain losses are caused by the effects of rain rather than by the actual rainfall, it becomes pertinent to inquire whether or not these effects can in some way be mitigated so as to reduce the time which ordinarily must elapse from the cessation of the rainfall until operations can be resumed. Similarly, equipment will fail to function or break down, materials will fail to arrive according to scheduled orders, men will quit, and a hundred and one other things can and do happen to delay or prevent the pouring of concrete. The total of the time losses from all these various causes is even greater than the total weather losses, and therefore these also deserve careful consideration.

PREVENTABLE AND UNPREVENTABLE LOSSES

As a matter of practical consideration, the time losses and delays incident to present methods of concrete-road construction may be divided into those which can be prevented and those which can not. But such prevention as may be possible can only be had by the exercise of considerable thought and attention and at some cost. The problem therefore becomes, in part, one of balancing the probable losses against the probable gains.

Table 3 gives in detail the time losses on a typical job during a period of three weeks. On this project there were a number of time losses, amounting in the aggregate to 43½ hours, which a little foresight and careful attention on the part of the management would have entirely eliminated or greatly reduced. For example, the spare mixer cable could just as readily have been carried with the mixer as left at the main office, and the wait of an hour and a quarter could thus have been eliminated without extra cost. Similarly, when the new cable was installed the clamps could have been properly tightened just as readily as not and 3 hours and 50 minutes of further loss could thus have been prevented. On the other hand, a few planks to bridge the heavy trucks over occasional soft spots in the subgrade would have required some outlay in the first instance and would have entailed some expense for keeping them with the outfit and available as needed, but this expense would have been small in comparison with the value of the 3½ hours lost because of their absence. Table 4 contains a summary of the time losses on this job for a period of four months, classified so as to group together those which were unavoidable on the one hand, and those which could have been avoided by intelligent management on the other.

Perhaps one of the major reasons why so few road contractors make any really systematic effort to reduce their time losses is that they do not know with any certainty the probability of such losses under given conditions. All contractors, of course, know that time losses and delays do occur and that they maker serious inroads into their expected or hoped-for profits. But, in general, such disruptions of their production plans or schedules are usually charged simply to luck or to the impossibility of foreseeing or preventing them.

Yet a number of such disruptions and delays can be shown to have a sufficiently high probability to be worthy of very serious consideration. Table 2, which is a summary of the time losses on 32 projects for more or less extended time periods, shows that while no two jobs suffered exactly to the same extent or in the same way, yet none escaped losses of rather serious proportions. The most common losses were from rain and wet subgrade even on jobs which ran for comparatively short periods during midsummer, but all weather losses together and the moving loss, which is generally unavoidable, account for only a little more than half of the total delay on the average project. Of the other losses, which are largely avoidable, the most serious were those caused by lack of prepared subgrade, by insufficiency or breakdown of the hauling equipment, by lack of materials, and by mixer and water troubles. Of the 32 projects listed in Table 2, 27 suffered to a greater or less degree from lack of prepared subgrade, 23 from insufficiency of hauling equipment, 14 from material shortage, 25 from mixer trouble, and 24 from water trouble.

There are therefore three important questions confronting the contractor: (1) The kind, persistence, and extent of his present time losses; (2) the cost of such losses; and (3) the cost and certainty of the measures which may be adopted to eliminate or reduce the loss.

No two jobs exhibit exactly the same conditions. The data presented in this paper merely illustrate tendencies and possibly indicate very roughly the average probabilities. Each contractor should keep an accurate daily record as to the amount and cause of all losses, and this record should be summarized weekly, monthly, and for the job and season. Such data will soon form a real working basis from which to judge the value of efforts to reduce the losses shown to be occurring on his own jobs. General averages as well as particular data from jobs other than his own, unless all the attendant conditions are known, are apt to prove misleading if they are considered as other than general indications of the possibility of loss.

TIME LOSSES EXPENSIVE

Many contractors fail to realize the actual extent of the losses incurred when production is interrupted. The amount appearing on the pay roll is usually

TABLE 3.—*Time losses on a typical job classified as avoidable and unavoidable*

Date	Time losses: Unavoidable	Time losses: Avoidable	Cause
	Hrs. Min.	*Hrs. Min.*	
July 5	----------	1 00	Lack of subgrade.
	----------	2 15	Finishing machine off of forms; poor forms.
July 6	----------	1 30	Water pump out of order.
	----------	30	Late start.
	----------	3 00	Mixer operator sick; no substitute provided.
	1 30	----------	Rain.
July 7	10 30	----------	Wet subgrade.
July 8	3 30	----------	Do.
	5 45	----------	Rain.
July 9	10 30	----------	Wet subgrade.
July 10	6 45	----------	Do.
	----------	1 00	Setting forms.
July 11	----------	1 30	Soft spot in subgrade; no planks available.
	----------	2 00	Roller trouble due to neglected repairs.
July 12	----------	40	Lack of subgrade.
	----------	20	Water trouble.
	3 30	----------	Gasket blown on mixer engine.
July 13	----------	30	Water-pump trouble due to neglected repairs.
	----------	1 00	Resetting forms; faulty engineering.
	1 00	----------	Moving mixer over bridge.
July 14	----------	45	Lack of subgrade.
	----------	1 15	Water trouble.
July 15	--------	45	Do.
	-------	1 15	Mixer cable broken; had to send 4 miles for new cable.
	1 30	----------	Replacing mixer cable.
	----------	1 00	Lack of subgrade.
July 16	----------	1 00	Water trouble.
	----------	4 00	Lack of subgrade.
July 17	----------	3 45	Do.
	----------	30	Finishing-machine trouble; poor forms.
July 19	----------	1 00	Water trouble.
	----------	1 30	Finishing-machine trouble; poor forms.
	----------	1 00	Mixer cable pulled loose; not properly tightened when installed.
July 20	----------	1 30	Mixer cable again pulled loose.
	----------	15	Loader trouble.
	----------	30	Lack of subgrade; fault of inspector.
	----------	30	Water trouble.
	----------	30	Finishing-machine trouble; poor forms.
July 21	----------	1 00	Soft spot in subgrade; no planks available.
	----------	1 00	Lack of trucks.
July 22	----------	1 00	Cleaning water tank.
	----------	1 00	Soft spot in subgrade; no planks available.
	----------	15	Loader trouble.
July 23	----------	30	Truck mired down at stock pile.
	----------	15	Mixer out of gas.
	----------	15	Poor inspection.
July 24	----------	1 20	Mixer cable pulled loose again.
	----------	40	Lack of subgrade.
Total	44 30	43 30	

TABLE 4.—*Analysis of time losses during the working season on one job from May 25 through September 25, 1926* [1]

	Hrs.	Mins.
Total time mixer operated during the construction season	447	50
Time lost in avoidable delays:		
Water trouble: Old water pumps; old 2-inch pipe line and inadequate supply of pipe line	87	30
Preparing the fine grade ahead of and in the rear of the mixer	62	3
Truck shortage	32	35
Improper subgrade drainage	35	30
Mixer trouble	19	0
Making unnecessary move with paving outfit	17	0
Repairing old, worn-out subgrade roller	9	30
Poor engineering and inspection	9	0
Using old forms that would not support the finishing machine	7	55
Getting late start in morning	5	40
Miscellaneous delays	4	12
Outfit stopped work for an expected rain; no rain came	2	45
Setting up new finishing machine	2	30
Using 2 old worn-out finishing machines	1	40
Loaders at loading plant		45
Total avoidable delay	297	35
Total time mixer should have operated during the construction season	745	25
Time lost in unavoidable delays:		
Wet subgrade due to previous rain	297	25
Rain during working hours	53	0
Moving outfit to new location	54	15
Mixer, mechanical trouble	13	10
Miscellaneous delays	1	15
Total unavoidable delay	419	5
Total number of working hours in construction season from May 25 to Sept. 26, 1926 (average length of working day, 10 hours 30 minutes)	1,164	30
	Miles	
Total production during construction season	8.56	

[1] Delays of less than 15 minutes duration occurring during the hours that the mixer was in operation are not shown in this analysis.

accepted as the measure of these losses, whereas it is far from the true measure. On a job on which the pay roll amounts to only from $200 to $300 a day, the total fixed charges which must be met during the working season may readily amount to from $15,000 to $20,000. Included in these fixed charges, in addition to the straight-time or continuing pay roll, are the interest and depreciation on plant and equipment which, on a modern job involving pavement construction only, may readily exceed $50,000 and even reach $100,000. As improved equipment is constantly being introduced and as the up-to-date contractor feels that he must keep step with such improvements, the amount of the fixed charge for equipment is a product of obsolescence rather than wear and tear, and depreciation is properly chargeable on a straight-time rather than an actual operating-time basis. And the same is true of the other fixed charges, including insurance, taxes, truck licenses, the cost of securing the job, and getting to and from it, and no inconsiderable part of the pay roll—all are practically fixed for the season and independent of the number of hours of actual production.

All these costs and expenses as well as the profits expected must be earned during the hours of actual production; and, as has been stated, the fixed charges may readily amount to from $15,000 to $20,000. Consequently, if concrete can be poured during 1,000 hours the fixed costs will average somewhere between $15 and $20 per hour; and if only 500 hours can be so utilized during the season the hourly charge to pay these fixed costs must be raised to $30 or $40 per hour. Obviously, with fixed charge so heavy little or nothing is left for profits, even though the hourly rate of production be fairly high. Hence it follows that every hour of available time which can be converted from non-production into normal production represents a very definite financial gain to the contractor.

Some kinds of time losses are more expensive than others. Thus, interruptions to actual production, such as waiting for trucks or trains to deliver materials, waiting while subgrade is prepared or while a break in the water pipe line is being repaired, usually involve full-time payment of the entire crew; whereas full or half day lay offs because of more prolonged interruptions, such as rain and wet subgrade, failure of materials to arrive at the yard or serious breakdowns of the controlling equipment, usually involve only the full-time payment of a comparatively small portion of the personnel. If, therefore, the lay off is not protracted it may be less expensive than the numerous short-time interruptions which occur during the working day. If, on the contrary, it is prolonged, men are apt to quit and the organization otherwise becomes more or less disrupted and then a serious loss results. Very rarely do we find production during the first day after a protracted period of idleness proceeding at its normal rate. Sometimes the effect is clearly apparent for two or three days.

LOSS CAN BE REDUCED BY CAREFUL MANAGEMENT

To what extent and with what degree of success the various kinds of time losses can be reduced will depend very largely on the ingenuity and resourcefulness exercised by the management. Poor management is certain to produce proportionately large time losses. Conversely, the employment of a really high-grade, able job superintendent is the best insurance against excessive losses from these causes as well as the best and probably the only road to really consistent and efficient production.

Intelligent production managers have long sought to prevent, or at least to reduce, interruptions and delays through a careful planning of the details and sequence of every operation, together with an intelligent forecast of the difficulties which may be encountered and the means to be adopted for their elimination. In such work it is not uncommon to find considerable expenditures devoted entirely to decreasing or preventing the possibility of certain probable delays or interruptions. The justifiable limit of such expenditures is dependent on the cost which such interruptions or delays would incur, the probability of their occurrence, and the degree of certainty with which they can be decreased or eliminated. In other words, expenditures of this kind are wise and profitable up to some point less than the lower limit of their actual insurance value. Beyond that point it is better to accept the loss if it comes than to make the relatively large expenditures necessary for reducing the probability of its occurrence.

To some extent these modern management methods in regard to interruptions and delays to production are in general use in concrete road construction. Thus, cement and often sand and stone or gravel are ordered well in advance of all probable construction requirements as a simple matter of insurance against delays due to the possible failure of such materials to arrive in exact conformity with the construction requirements. The cost of the extra handling, interest charges, stock-pile losses, etc., are often considerable. Yet many contractors find the incurrence of these extra costs a profitable venture. Many contractors also make it a practice to carry in stock on the job a supply of certain repair parts for the controlling equipment, and find that they are able thereby greatly to reduce many delays that otherwise would prove long and costly.

These are some of the lines which concrete road contractors have rather generally adopted in their efforts to insure continuity of production. Whenever intelligently applied in conformity with the requirements of the particular job the results have generally been satisfactory. The data assembled by the Bureau of Public Roads during the past two years clearly show the benefit of such precautions and point to other fields in which modern management methods might possibly find further extension with equally beneficial results.

SUBGRADE DRAINAGE SAVES MONEY

Examples of points at which a beginning for such extension might be made will readily come to mind. Thus, on one job during the past summer 35½ hours of possible mixer operation were lost because of the continued failure to provide means for subgrade drainage. Forty cents worth of common labor each day of the hundred or more in the working season would have made ample provision for any water which might fall during the night to escape to the side ditches. But no provision was made, with the result that during each rain water collected between the forms as in a pond until such time as men could be sent out to dig the necessary outlets. During one 10-day period this occurred three times. Here, then, is a case where about $50 worth of common labor plus a small amount of direction and forethought would have saved the contractor during the season at least 35 hours for additional production—worth in this particular case at least $1,200. This one item may also offer some explanation as to why this contractor out of a total of 1,164½ available hours from the opening of the season until September 26 succeeded in utilizing only 448 hours in actual production. Of the total time losses, 386 were charged to rain and wet subgrade, although rain actually fell only during 53 hours of the working time. Further details of this project are given in Table 4.

It is in meeting and overcoming conditions of this kind that intelligent, resourceful management will find its greatest field of economic usefulness. Better methods for providing surface drainage as well as for handling the actual operations of subgrading and form setting with a view to mitigating the effects of rainfall are undoubtedly possible. Such methods might, in the first instance, be considerably more expensive than the prevailing methods and yet prove economical providing they can be shown to be dependable in materially reducing the time losses below the normal expectancy under present methods.

Frequently the roads over which the materials for new construction must be hauled are unimproved or in a very bad state of repair. Roads of this kind require a considerable amount of well-directed, systematic maintenance to make possible such orderly operation of the hauling equipment as will eliminate mixer delays without the use of a large oversupply of trucks. Such maintenance is also usually essential to the early resumption of hauling after rains. Yet, in spite of these well-known prerequisities and the further well-known fact that such maintenance will often more than pay for itself in lower hauling costs and less wear and tear to the equipment, one rarely finds a contractor who makes even a pretense of systematic maintenance. In the few cases which came under the observation of bureau representatives, where maintenance was attempted it was generally assigned to some one entirely without experience in the work. Possibly it is the fact that this is generally the case that is responsible for the idea, firmly established among road contractors, that the maintenance of unimproved roads will not pay. The probability that it will pay if it is properly handled is indicated by the fact, that, on the typical projects observed by the bureau representatives during the past two years, an average of 8.6 per cent of the total time losses was caused by the hauling equipment. This does not include the time losses due to the road being too wet or soft for hauling, although the subgrade was dry enough to permit the pouring of concrete. The total losses suffered under this condition are not known. As the distinction is rather difficult to make, such losses are generally charged to rain and wet subgrade. However, there was one job on which the distinction was made; and on that job, which showed about an average distribution of time losses, more than 10 per cent of the total losses charged to rain and wet subgrade were really due to the fact that the hauling road was too wet or soft for operation of the hauling equipment. On this job the contractor lost about $150 per month because the road did not dry sufficiently fast to permit hauling as soon as the subgrade was dry enough for pouring concrete. Careful, systematic maintenance would, no doubt, largely have eliminated this loss.

OTHER PREVENTABLE LOSSES

Moving from one set-up to another during the working season seems to consume much more time than is generally believed. The average for all the jobs studied during the past two years was 10.1 per cent of the total time losses, the second largest item on the list. Sometimes more moves are made than conditions really warrant. The economic factors involved in determining the number of set-ups which should be made on a given job are fully discussed in previous issues of this magazine.[2] The amount of time consumed in making these moves, however, seems to be so large that a considerable reduction should be possible when the contractor fully understands the actual, monetary loss incurred every day his equipment is nonproductive. In selecting equipment one of the factors which should be given careful consideration is that of mobility or ease of dismantling, transporting, and reassembling, not only of individual units but also for the entire plant. The various details of the entire operation of moving should be planned as carefully as the operations involved in the placing of the concrete.

Waiting for the subgrade to be prepared accounted for 9 per cent of the total time losses on the projects studied. These losses should be possible of entire elimination. With very few exceptions they are wholly chargeable to poor management. On the average job, as shown by these studies, their entire elimination would be worth from $2,000 to $3,000 per season—a sum sufficient to more than pay the difference in salary as between a poor and a good superintendent.

The remaining time losses, such as those due to poorly operated or insufficient hauling equipment, mixer trouble, lack of materials at the supply yard, water supply, and the various miscellaneous causes, all of which comprise about 33 per cent of the total average time losses or about 16 per cent of the total available time, are also very largely a question of management. Few, if any, of these losses can be entirely eliminated without incurring excessive expenditures. But there would seem to be little reason to doubt that all can be reduced and some very materially. This is shown so clearly on the observed jobs on which the management was of an especially high order as to be subject to little or no question.

Thus, on one job blessed with an exceptionally able superintendent but otherwise fairly typical of the many jobs studied, the total time losses from all causes during the period from April 22 to September 18, inclusive, consumed less than 30 per cent of the total available working time as compared to 47 per cent for the average job. (See Table 2, project 8.) As the season was rather rainy and the soil a heavy clay, the losses due to rain and wet subgrade were about average, or 21.6 per cent. Moving from one set-up to another, or from one section to another, also required about the normal amount of time; but all other time losses were reduced to a remarkably low percentage, and some were eliminated entirely. Thus no time was lost waiting for subgrade to be prepared nor from faulty operation of the mixer, nor because of the water supply. In fact, the total time losses on this job during the period indicated from all causes other than rain, wet subgrade,

[2] "Efficiency in Concrete Road Construction," PUBLIC ROADS, vol. 6, Nos. 9, 10, 11, 12; vol. 7, No. 1.

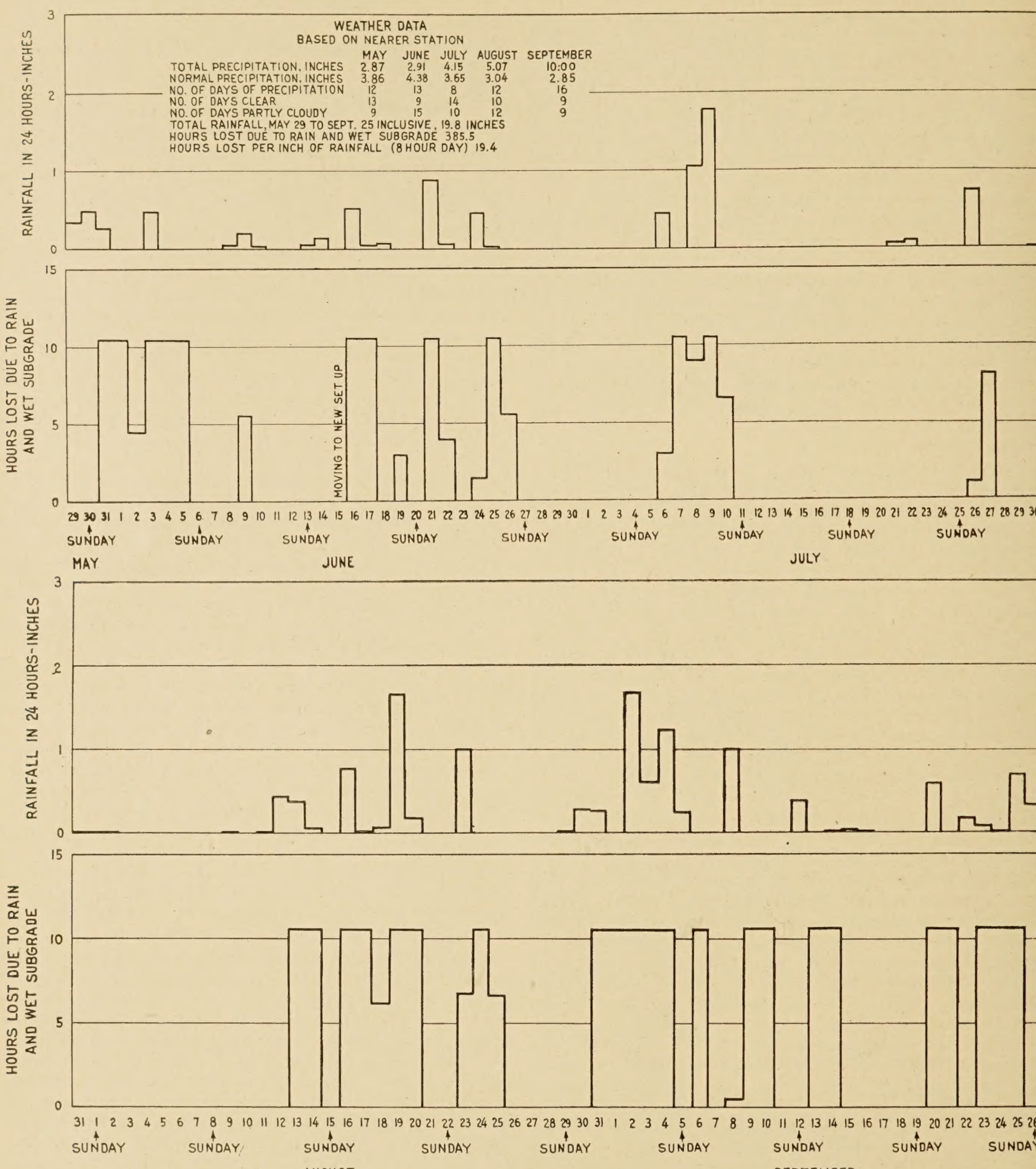

Fig. 1.—Rainfall and Time Losses from Rain and Wet Subgrade on Job Near Columbia, Missouri, from May 29 to September 25, 1926

and moving amounted to only 2 per cent of the total potentially available working time as compared with 20 per cent of the available working time lost from these causes on the average job during the season.

Even in the short working season, of 1,500 available hours, this decrease of the nonproductive time from 300 hours for the average job to only 28½ hours on this particular job represented an actual money value of more than $8,000 if we consider only the direct loss the firm would have sustained if the outfit had remained idle the longer period. But on this job the rate of production was exceptionally high, not just for short periods but was so maintained consistently throughout the entire season. Thus ever hour of available working time utilized in actual production doubtless represented a considerable profit. While this project

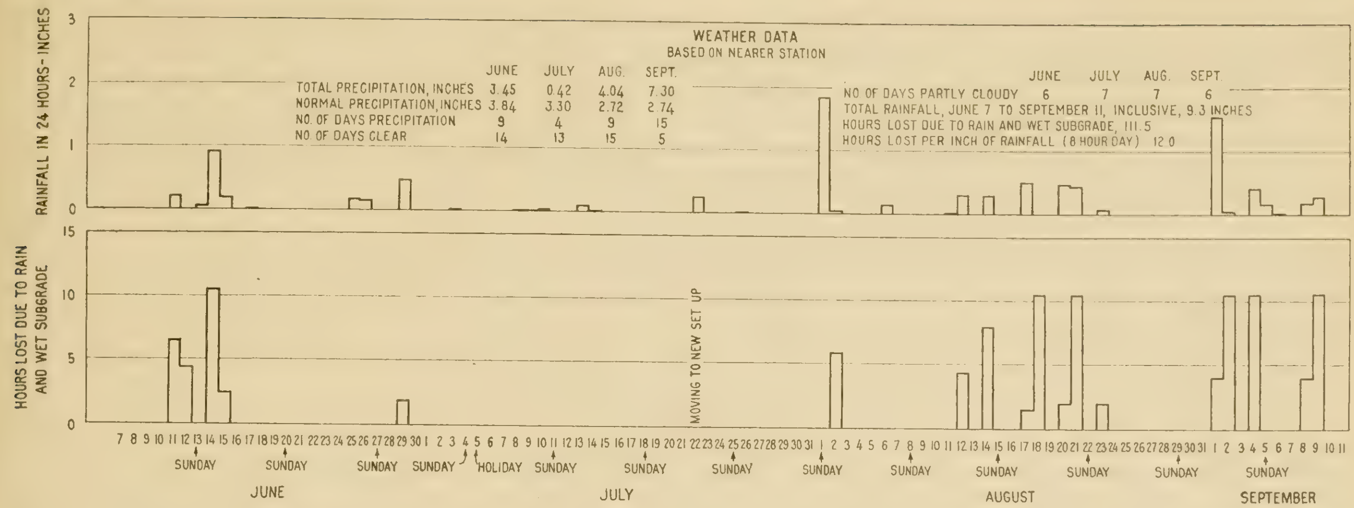

FIG. 2.—RAINFALL AND TIME LOSSES FROM RAIN AND WET SUBGRADE ON JOB IN BOWIE COUNTY, TEXAS, FROM JUNE 7 TO SEPTEMBER 11, 1926

TABLE 5.—*Time losses, in hours, in summer and fall*

Project No.	Dates (inclusive)	Available working hours: Mixer in operation	Available working hours: Mixer idle	Lost time: Rain, wet subgrade, etc.	Moving	Subgrade not prepared	Hauling equipment	Lack of materials	Mixer trouble or repair	Water	Cold weather	Finishing	Miscellaneous
13	July 1 to 31	212.5	74.5	46.0			2.0		16.0			2.0	8.5
	Oct. 1 to 31	76.0	215.0	171.0			1.0		3.0		40.0		
19	July 1 to 31	188.5	72.0	28.0		10.75	2.75	21.75	4.75	53.0		1.0	
	Oct. 1 to 31	117.5	146.0	39.0	38.0	1.0	22.25	28.0	9.5	2.0		0.75	5.5
15	July 1 to 31	186.0	99.0	12.0	53.0	13.0	10.0		2.0	8.0			1.0
	Oct. 1 to 31	134.0	265.5	150.0	32.0				36.5		47.0		
16	July 1 to 31	155.0	142.0	22.0	69.0		29.5		21.5				
	Oct. 1 to 31	110.5	206.5	127.0	20.5	9.0	13.0		8.0		3.0		26.0
17	July 1 to 31	165.75	104.25		66.75		25.75		7.75	4.0			
	Oct. 1 to 31	118.0	169.0	79.0	10.0		17.0				63.0		
	Grand total	1,463.75	1,493.75	674.0	289.25	33.75	123.25	49.75	109.0	17.0	153.0	3.75	41.0
	Total for July	907.75	491.75	108.0	188.75	23.75	70.0	21.75	52.0	15.0		3.0	9.5
	Total for October	556.0	1,002.0	566.0	100.5	10.0	53.25	28.0	57.0	2.0	153.0	0.75	31.5

offers the most outstanding example of the benefits of good management so far encountered, it differs from several others only in degree. All the studies indicate that the relative size of the preventable time loss recorded is a fairly good indication of the quality of the management on the job. Poor management seems to be invariably associated with relatively large preventable or reducible time losses, while under able management these time losses are reduced to relatively minor importance.

WHAT OF THE WEATHER LOSSES?

Rainfall and its effects on the subgrade and the road or track over which the materials are hauled, together with frost and cold weather, was the cause of nearly one-half of the average time lost on all jobs studied. These losses naturally vary greatly from job to job. A sandy or gravelly, porous soil will dry far more quickly than a heavy clay or silt. The amount and distribution of rainfall also differs from place to place. No constant relation between the amount of rainfall and the time lost because of rain and wet subgrade is therefore to be expected. However, it may be possible under given conditions to approximate the probable loss of time by consultation of past rainfall records, and such a forecast is valuable as an estimating guide even if nothing can be done to reduce the time loss.

To ascertain what relation existed on the projects observed a number of them were selected for special study with this point in mind. No attempt was made to measure the rainfall actually occurring on the job; but data were obtained from the nearest weather station for the period of the job. In some cases the stations were located very close to the job. But, as rainfall often varies considerably in a short distance, there can be no definite assurance that the records represent the exact rainfall as it occurred on the road. Nor is assurance necessary. The contractor or superintendent who wishes to learn something of the weather that may be expected on a prospective job in order that he may make a suitable allowance for delays and be prepared to meet and overcome the resulting difficulties generally will have no more definite source of information than the past records of the nearest weather recording station. As kept by most stations, these data show the rainfall, temperature, and state of weather during each 24 hours, and the normal or average condition for each month—all of which may be of importance in forecasting the probable conditions on any given job.

Figure 1 shows the weather and rainfall during the past season on one road that was largely on new location. The soil beneath the surface was fairly heavy clay on the hills and heavy silt or gumbo along the streams. About the only indicated relation is that a half inch or more of rainfall caused a delay of at least one entire working day. Smaller rainfall, if limited to one day, apparently caused relatively large or small time losses depending on the time of day when it

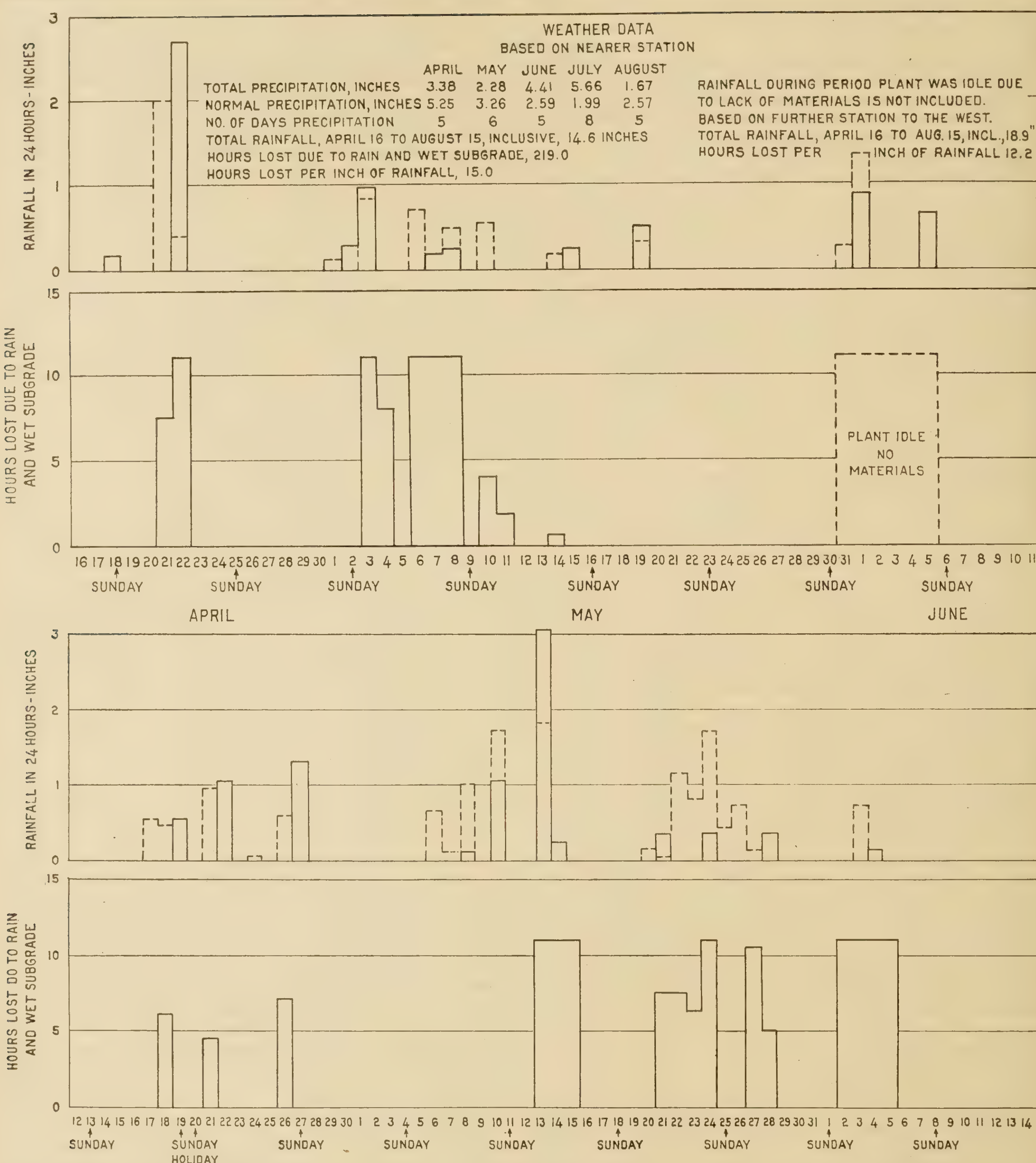

Fig. 3.—Rainfall and Time Losses from Rain and Wet Subgrade on Job in Bowie County, Texas, from April 16 to August 15. Rainfall at Nearest Station to the East Shown by Full Lines and that at the more Distant Station to the West Shown by Dash Lines

occurred. For the period May 29 to September 25, inclusive, we find that an average of 19.4 hours working time were lost for each inch of rainfall.

Figure 2 shows another job located on an old right of way and a somewhat lighter soil. Here, apparently, a rainfall of nearly ¾ of an inch was necessary to cause a delay of a full working day. Here also, for the period involved, the average time lost per inch of rainfall was only 12 hours.

Figure 3 shows the rainfall as recorded at two stations between which another project was located. It will be noted that the rainfall was considerably different at these two stations and that the time losses on the project do not correspond very closely to what would be expected from the rainfall measured at either station. The last time loss of three full days was largely due in the first part to a local rain which did not extend to either station. Based on the rainfall as

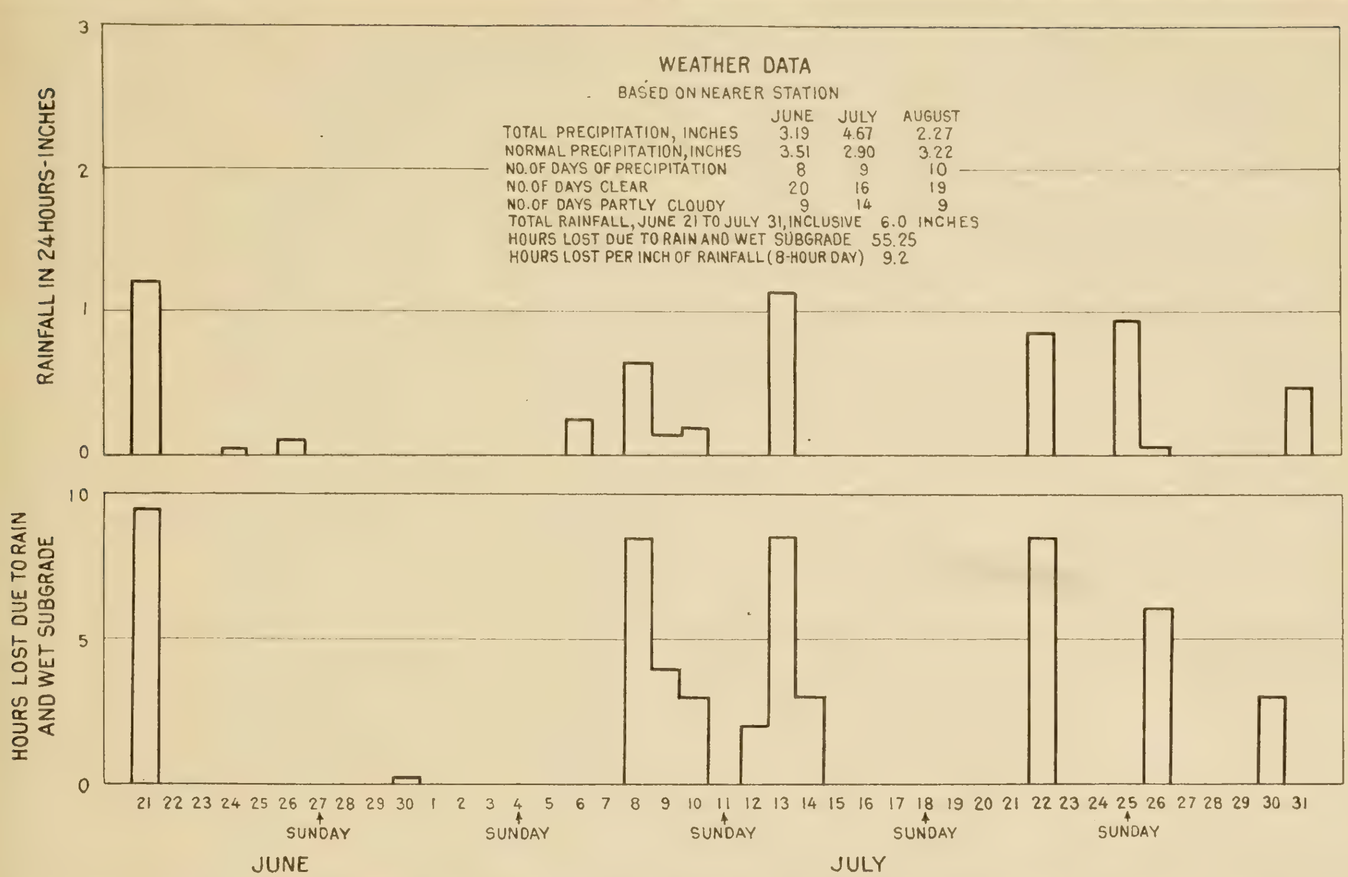

FIG. 4.—RAINFALL AND TIME LOSSES FROM RAIN AND WET SUBGRADE ON JOB NEAR GUTHRIE, OKLAHOMA, JUNE 21 TO JULY 31, 1926

recorded at the nearest weather station, and eliminating the time loss due to the local rain, we find that each inch of rainfall during the period involved caused an average loss of 15.0 hours of working time while if we use the rainfall at the other station as a basis only 12.2 hours of working time were lost per inch of rainfall. Figure 4, illustrates further the relation between rainfall and the working time lost to actual production.

FALL WEATHER LOSSES LARGE

There are so many variable factors which enter into the relation between rainfall and time losses that the data so far available from the present studies warrant no definite conclusions except in regard to one point; namely, that an equal amount of rainfall and equal distribution under a given condition will cause a much longer delay in the fall or early spring than in the summer. Consequently, the contractor who permits possible hours of summer operating time to escape in the hope of making up lost time by operating a little later in the fall or starting operations a little earlier the next spring is gambling against heavy odds. Table 5 gives the time losses on a number of fairly typical jobs for the months of July and October, respectively. Here we find that in spite of numerous attempts to work overtime on good days in October the time losses averaged 64 per cent in October as against 35 per cent in July for these jobs. This difference is almost entirely due to the time losses caused by rain, cold weather, and wet subgrade.

The time of day at which rainfall occurs, its intensity or duration, as well as the time between rainfalls probably under some conditions affect the amount of time lost more than the actual amount of the rainfall. Comparatively small rainfall occurring during working hours will stop work and if falling on a subgrade but little past the point permitting work will generally cause a much longer delay than the same amount falling under identical conditions except on a thoroughly dry subgrade.

Although the data herein presented are not sufficient to warrant definite conclusions, they do indicate that certain very similar conditions exist on many projects, and that these conditions have a tremendous influence on the actual cost of the completed work. They indicate also that nearly half of the average time losses are due to causes which are or can be made subject to the control of the contractor. With increasing skill and ability in management we may expect to find this type of time loss reduced in the future. The other half of the losses due directly and indirectly to adverse weather conditions it is clearly impossible to eliminate entirely and such losses are therefore amenable only in part to managerial control. All of the data so far assembled, however, seem to indicate that a goodly proportion of the time lost now as the direct or indirect result of rainfall is not inherent in the nature of the physical conditions, but rather, at least in part, is due to difficulties inherent in or connected with the present methods of operation and management. Therefore as the probability ratio of the various forms of loss and the financial burden they place upon the contractor become better known, the faults of our present means and methods will surely be corrected.

If, under certain conditions, we find that on the average $50 worth of attention to surface drainage of the prepared subgrade is reasonably certain to save for

(Continued on page 208)

TESTS OF CONCRETE CURING METHODS

A PROGRESS REPORT OF EXPERIMENTS CONDUCTED BY THE BUREAU OF PUBLIC ROADS

Reported by J. T. PAULS, Highway Engineer, United States Bureau of Public Roads

FOR THE purpose of obtaining information as to the effect of moisture and temperature changes in concrete road slabs immediately after laying, and to determine the effect of various curing methods and subgrade friction on the concrete, the Bureau of Public Roads built, during August, 1926, at Arlington, Va., a series of 40 concrete slabs, each 200 feet long by 24 inches wide and 6 inches thick. The concrete was of 1 : 2 : 4 mix with Potomac River sand and Potomac River gravel as aggregates. The mixing and placing were done under weather conditions as nearly identical as possible. A view of the slabs in place is shown in Figure 1.

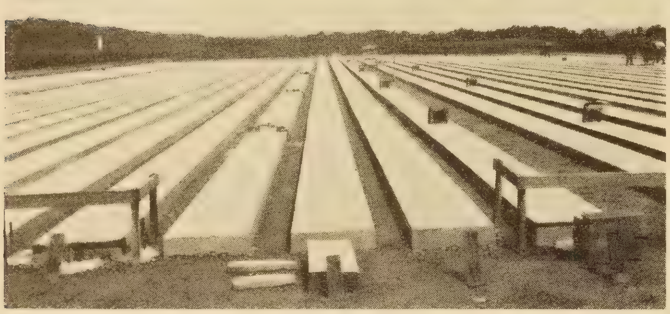

FIG. 1.—GENERAL VIEW OF THE EXPERIMENTAL SLABS AT ARLINGTON, VA.

The plan of construction and curing, as detailed in Table 1, covered a wide range of variables so that, after sufficient time and study, information should be available which will permit a better understanding of the following subjects:

1. Comparative effect of different methods of curing.
2. Effect of steel reinforcing of various types and weights in distributing stresses resulting from shrinkage in the concrete.
3. The effect of expansion joints in distributing stresses resulting from shrinkage in the concrete.
4. The effect of moisture in the subgrade in reducing shrinkage cracking.
5. The effect and prevention of rapid drying of the newly placed concrete.
6. The magnitude and effect of subgrade resistance.
7. The curling of concrete pavements.
8. The possible relation between pavement behavior and test data from control specimens.

TABLE 1.—*Details of construction and curing of the experimental slabs*

Slab No.	Subgrade condition	Reinforcing	Length of segmental sections (feet)	Curing method
1	Dry	None	None	None.
2	do	do	20, 30, 40, 50, 60.	Do.
3	do	do	None	Tarvia B.
4	do	do	do	2 pounds calcium chloride.
5	do	do	do	Sodium silicate.
6	do	do	do	3 pounds calcium chloride.
7	Dry	None	None	Tarvia B; tar paper on subgrade.
8	do	2 ¼-inch deformed bars.	do	None.
9	do	2 ⅜-inch deformed bars.	do	Do.
10	do	2 ½-inch deformed bars.	do	Do.
11	do	2 ¾-inch deformed bars.	do	Do.
12	do	2 ¾-inch plain bars painted and greased.	do	Do.
13	do	2 ½-inch deformed bars.	20, 30, 40, 50, 60.	Do.
14	do	2 ¾-inch deformed bars.	do	Do.
15	do	None	None	2 per cent calcium chloride admixture.
17	do	43.8-pound mesh	do	None.
18	do	23.6-pound mesh	do	Do.
19	do	43.8-pound mesh	20, 30, 40, 50, 60.	Do.
20	do	None	None	Dry straw.
21	do	do	do	Dry earth.
22	Lightly sprinkled.	do	do	Wet earth.
23	do	do	20, 30, 40, 50, 60.	Do.
24	do	do	None	Wet straw.
25	Wet	do	do	Burlap and wet earth.
26	do	do	20, 30, 40, 50, 60.	Do.
27	do	do	None	Burlap and 2 pounds calcium chloride.
28	do	do	do	Burlap and sodium silicate.
29	do	do	do	2 pounds calcium chloride.
30	do	do	do	Sodium silicate.
31	do	do	do	2 per cent calcium chloride admixture.
32	do	43.8-pound mesh	do	Burlap and wet earth.
33	do	23.6-pound mesh	do	Do.
34	do	43.8-pound mesh	20, 30, 40, 50, 60.	Do.
35	do	2 ¼-inch deformed bars.	None	Do.
36	do	2 ⅜-inch deformed bars.	do	Do
37	do	2 ½-inch deformed bars.	do	Do.
38	do	2 ¾-inch deformed bars.	do	Do.
39	do	2 ½-inch deformed bars.	20, 30, 40, 50, 60.	Do.
40	do	2 ¾-inch deformed bars.	do	Do.
41	do	None	None	Asphalt emulsion.

Sufficient time has not elapsed since the investigation was started to make it possible at this time to give complete results. However, on a few of the problems studied sufficient indications have been obtained to warrant presentation at this time. These somewhat scattering data and preliminary indications are presented in the following paragraphs.

LOSS IN MOISTURE

Two methods were used to obtain the loss in moisture of the concrete. The first consisted of taking a pan of concrete (about 30 pounds) and weighing it as it came from the mixer; afterwards placing it in the sun and weighing at hourly intervals. In this manner the loss of moisture from the surface of the concrete, without curing, was determined.

The other method consisted of pouring slabs 24 by 12 by 6 inches concurrently with each long slab, and weighing the concrete as it came from the mixer. The slab was then cured in the same manner as the corresponding long slab, the edges of all the small slabs being painted after 24 hours with a heavy tar. In this manner the loss in moisture was limited to the surface and the base. The slabs were weighed 24 hours after pouring and at intervals thereafter. Figure 2 gives the moisture loss obtained under the several different conditions.

Curve A in Figure 2 represents the loss in weight of a slab laid on a dry subgrade and without any curing treatment. It can be seen from this curve that the greatest loss in weight and hence in moisture content occurred during the first 24 hours after pouring. Curve B represents the loss in weight of a similar slab laid on a wet subgrade, covered with wet burlap for 24 hours and wet earth for 13 days. This curve also shows that the greatest loss in moisture occurred during the first 24 hours after pouring. The loss in moisture in the slab laid on the dry subgrade without curing is approximately four and one-half times the loss that

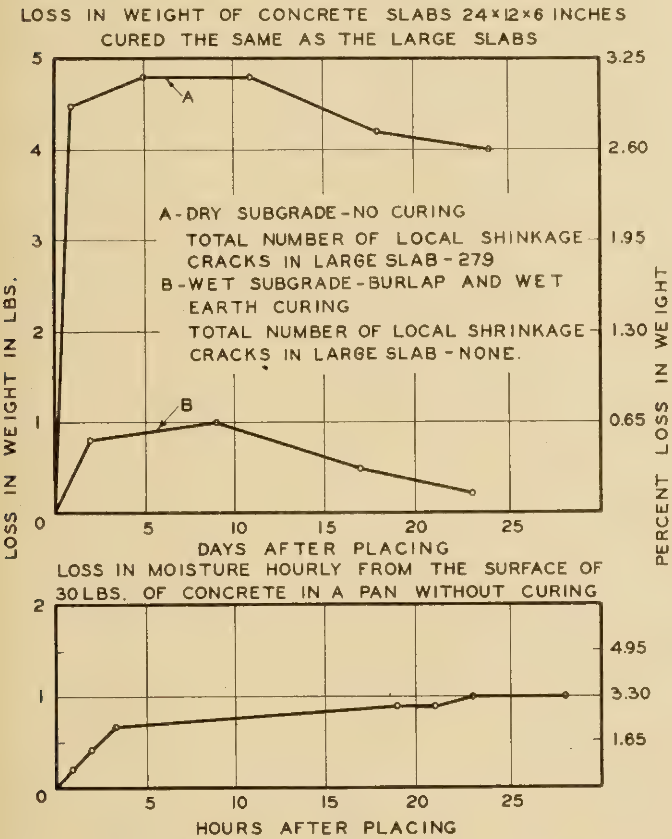

Fig. 2.—Diagrams Showing Loss of Moisture in Concrete

occurred in the slab laid on the wet subgrade and cured with wet burlap during the first 24 hours after pouring. The lower curve in Figure 2 represents the loss in moisture over a period of 28 hours, using 30 pounds of concrete, with evaporation limited to the surface. The greatest loss by this method was found to occur during the first three or four hours after the concrete was poured.

The effect on the concrete of the rapid drying out during the first few hours after placing is shown by the number of local shrinkage cracks occurring. In the slab with no curing 279 local shrinkage cracks developed, while none occurred in the slab which was covered with wet burlap during the first 24 hours.

It seems definitely indicated that the most important requisite of a satisfactory curing process is that it shall prevent or retard the drying of the concrete during the first full 24 hours after placing.

EFFECT OF STEEL REINFORCING

A series of reinforced slabs was included as one of the features of the investigation, the purpose being to determine the effect of the different sizes and types of steel on the distribution of stresses developed in the pavement under different conditions of curing from causes other than traffic.

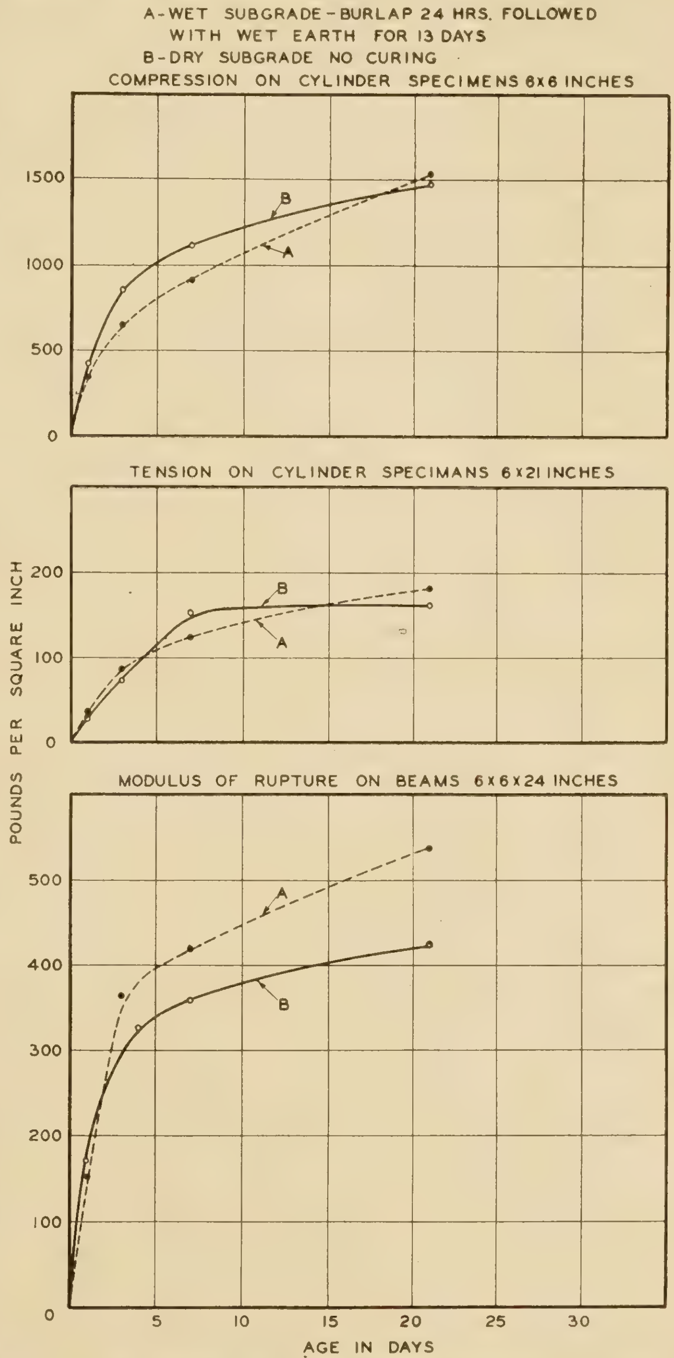

Fig. 3.—The Effect of Curing on the Strength of Control Specimens

Three types of reinforcing were used in the different slabs. They were: Deformed bars of several sizes placed continuously and segmentally; plain ¾-inch bars painted and greased; and rectangular mesh of 23.6 and 43.8 pound weights. All reinforcing was placed 3 inches below the surface of the pavement. In the case of the bar type, two rods were placed in each slab 12 inches apart and 6 inches from the edges.

Table 2 shows the coefficients of shrinkage obtained with several different types and quantities of reinforcing in comparison with the coefficient of unreinforced concrete. The shrinkage coefficient was determined from microscopic measurements of the width of the transverse cracks in the different slabs.

TABLE 2.—*The effect of reinforcing in reducing the thermal coefficient of expansion and contraction*

Slab No.	Reinforcing	Area of steel in the slab section	Number of transverse cracks	Average total width of transverse cracks	Average coefficient (per degree C.)
		Square inch		*Inch*	*Inches per inch*
1	None	None.	6	0.532	0.000011
8	2 ¼-inch deformed bars	0.130	4	.288	.0000066
9	2 ⅜-inch deformed bars	.20	4	.199	.0000045
10	2 ½-inch deformed bars	.386	15	.125	.0000024
11	2 ¾-inch deformed bars	.868	6	.023	.00000064
12	2 ¾-inch plain bars painted and greased	.910	6	.470	.0000095
17	43.8-pound mesh	.240	5	.108	.0000025
18	23.6-pound mesh	.132	3	.261	.0000061

These measurements show that certain types and amounts of reinforcing continuously placed greatly reduce the thermal coefficient of the concrete pavement.

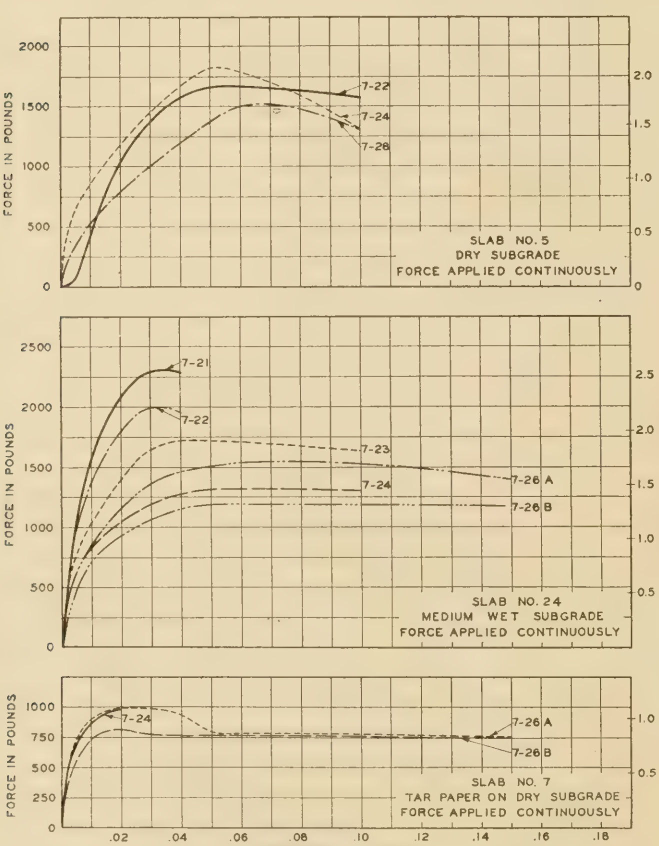

FIG. 4.—DIAGRAMS SHOWING RESISTANCE TO MOVEMENT OF SLABS BY DRY, WET, AND TAR-PAPER-COVERED SUBGRADES

The slabs reinforced with two continuous ¼-inch deformed bars and with rectangular mesh of 23.6-pound weight are found to have approximately the same coefficient, and it will be noted that the cross-sectional area of the steel in each case was nearly the same.

The greatest reduction in the shrinkage coefficient was obtained by the use of two ¾-inch deformed bars, and the minimum reduction—almost negligible in amount—was obtained with the use of two ¾-inch plain bars painted and greased.

TESTS OF CONTROL SPECIMENS

Compression, tension, and modulus of rupture specimens were made concurrently with and cured similarly to the large slabs. Specimens for compression were 6 by 6 inch cylinders; for tension, 6 by 21 inch cylinders; and for modulus of rupture, 6 by 6 by 24 inch beams. Two sets of each were made to be tested at 24 hours, 3, 7 and 21 days and 6 months.

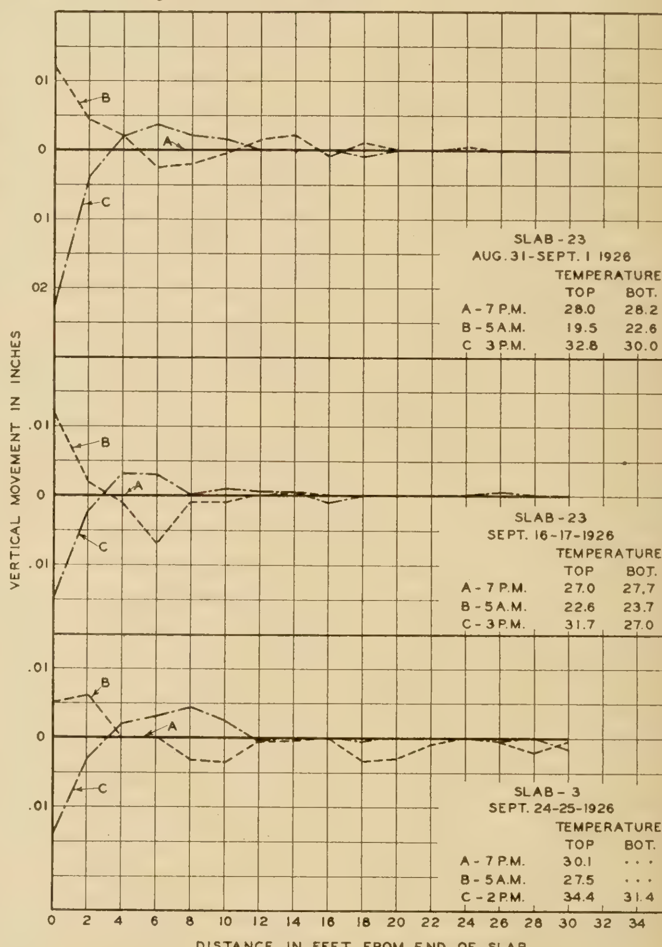

FIG. 5.—MEASUREMENTS OF SLAB CURLING

All of these, except the six-month specimens, have been tested at the present time, and the average strength curves for each type of test are shown in Figure 3. These results show that specimens laid on the dry subgrade without any curing reached a higher early strength than those laid on a wet subgrade and covered with wet burlap for 24 hours and wet earth for 13 days. As the specimens age, those made on the wet subgrade show a higher strength than those on the dry subgrade without curing.

SUBGRADE RESISTANCE

The resistance of the subgrade to the horizontal movement of the slab has been determined for several subgrade conditions. The value of this coefficient was obtained by measuring the force required to move

(Continued on p. 208)

RESEARCHES ON BITUMINOUS PAVING MIXTURES

Reported by W. J. EMMONS, Highway Research Specialist, United States Bureau of Public Roads

DURING the past year research on bituminous mixtures has been vigorously prosecuted by a number of organizations. Although attention at present is focused principally upon the development of a test which will define the resistance to displacement of any mixture when subjected to conditions of service, the basic motive behind all such research is the formulation of a rational theory of design or the substantiation of an existing theory.

At the Bureau of Public Roads two pieces of apparatus are in process of development which it is hoped will assist in the solution of the problem. Neither apparatus is perfected but it is felt that a description of the work being done will prove of interest at this time.

DISPLACEMENT DETERMINATOR

A machine which attempts to duplicate to a certain degree the action of traffic on a pavement surface has been designed for the purpose of determining the comparative strength or resistance to displacement of bituminous mixtures. Figure 1 shows in diagrammatic form the arrangement of this machine. The essential feature is a series of 11 steel cylinders or rolls, 4 inches in diameter by 3 inches long, mounted between and near the peripheries of two confining steel disks, which in turn are rotated by a motor. Beneath the rolls is a water-tight bath or tank in which is placed the specimen to be tested. At the beginning of the test the rolls are lowered gently to the surface of the specimen and the motor started. Rotation of the rolls takes place as they pass over the specimen, tending to deform it longitudinally. A certain amount of impact is also imposed as each roll leaves the specimen and the following one comes in contact with it. A small metal plate held lightly against the end of the specimen and connected with an Ames dial by a brass rod constitutes the device for measuring deformation.

The specimens are prepared by hand mixing and are compacted in a rectangular, collapsible steel mold by means of an electric hammer fitted with a square tamping end. Specimens 8 by 6 by $2\frac{1}{4}$ inches in size have been used in most of the work thus far, although at present the behavior of a smaller size of specimen, 8 by 4 by $2\frac{1}{4}$ inches, is being investigated. In each case the face of greater area is exposed to the action of the machine.

As might be expected, widely different test values may be obtained by varying the conditions of the test. An arrangement of the machine and of the specimen was sought which would give a wide range in strength

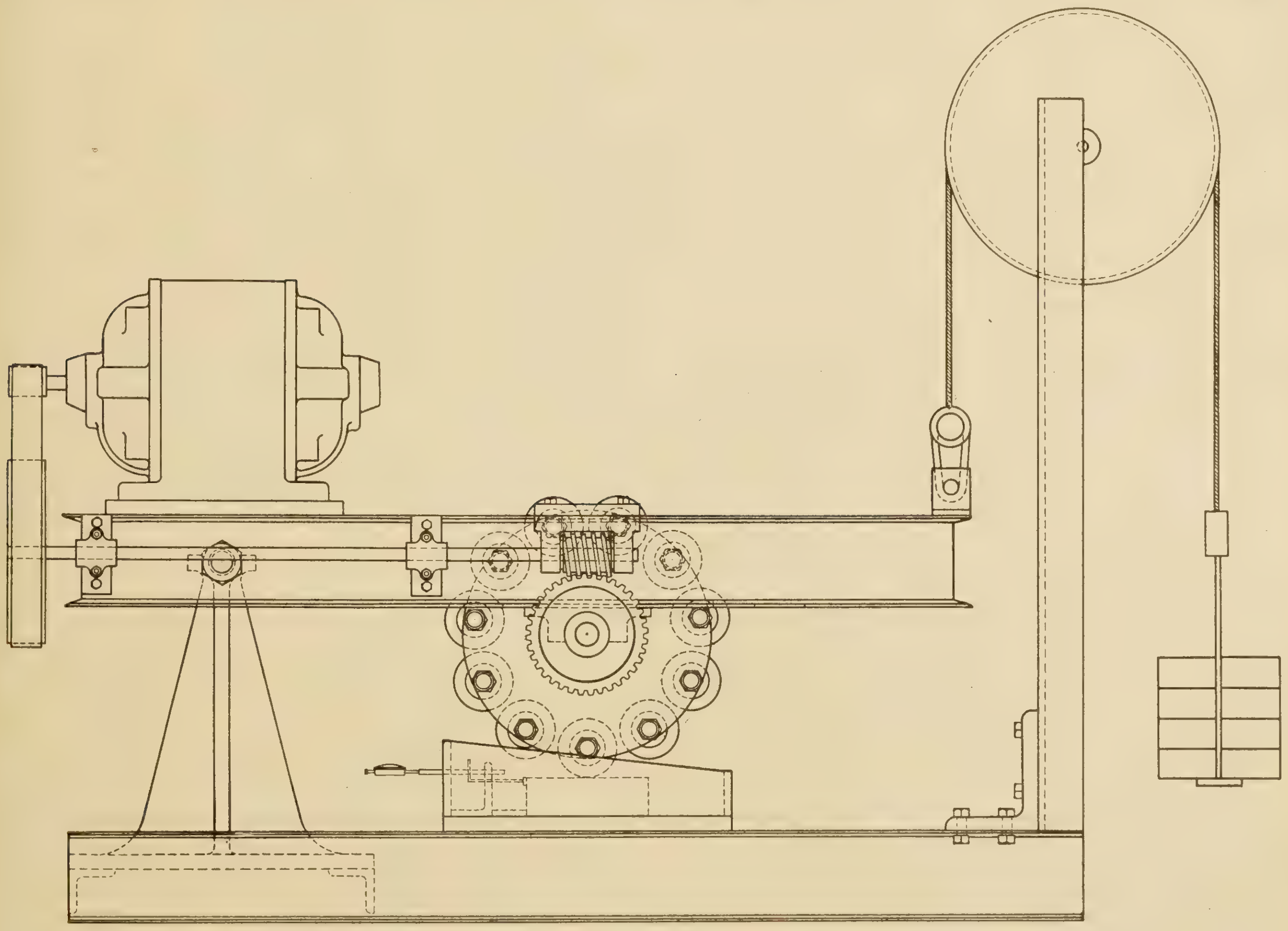

FIG. 1.—ROLLER MACHINE FOR TESTING BITUMINOUS PAVEMENT SPECIMENS

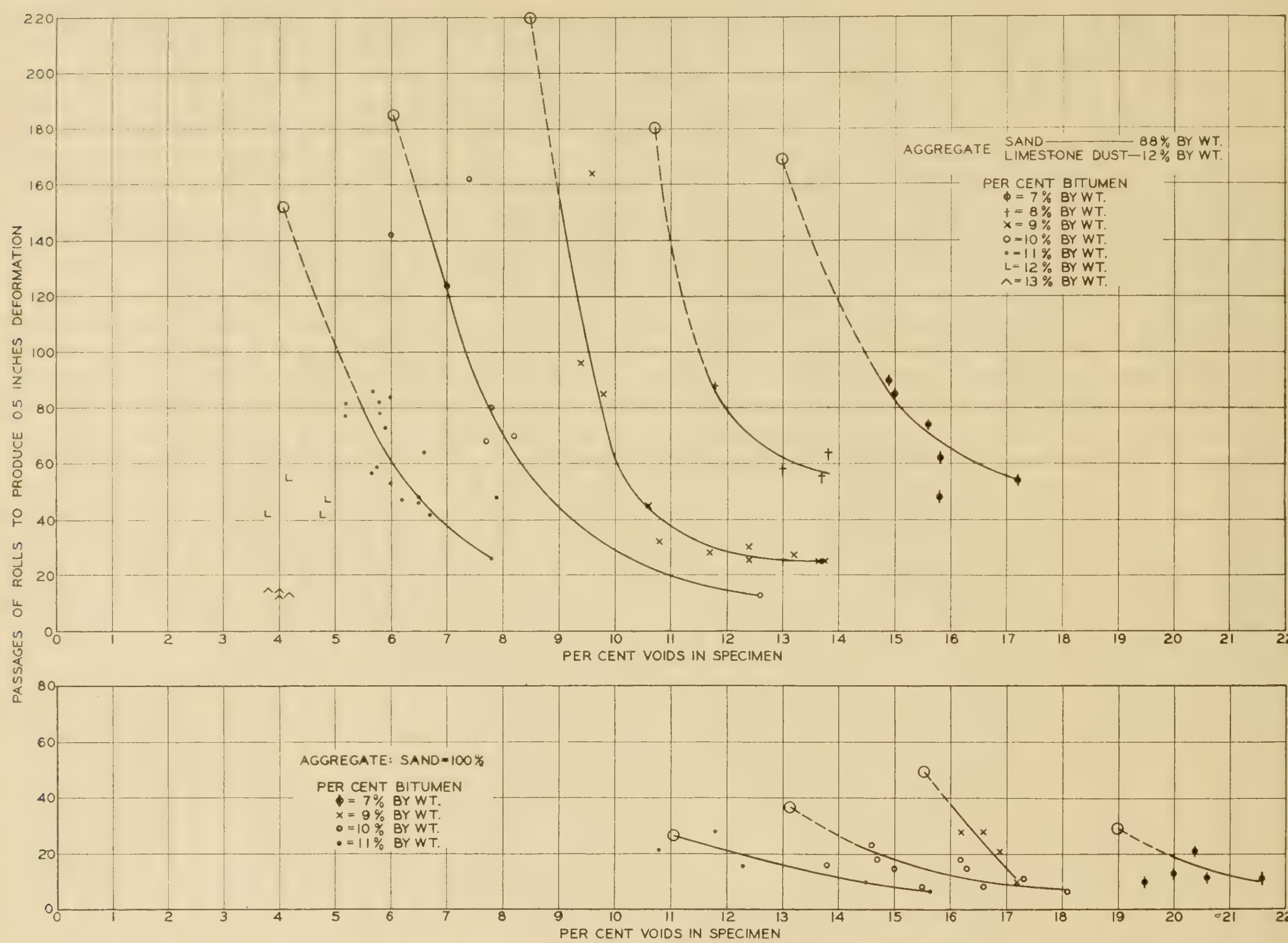

Fig. 2.—Relation Between Strength and Composition of Experimental Sheet Asphalt Mixtures

values between weak and strong mixtures. The weight imposed by the rolls is susceptible to adjustment by means of counterweights to a maximum of 450 pounds, and the speed of rotation may be varied from 4 to 10 revolutions per minute. The degree of support provided for the specimen under test greatly affects the results; and it has been found best to confine it in a frame at the rear and the two sides. The end toward which the movement takes place has at times been left entirely unsupported but it is probably better to insure againt slipping of the entire specimen by providing small plates partially closing the fourth side of the rectangle.

For the purpose of bringing out the effect of these many variables, rather than of deriving definite information regarding mixtures, many short series of tests have been run. The typical series shown in Figure 2 were made on 8 by 6 by 2¼ inch specimens, with a machine speed of seven revolutions per minute, a load of 250 pounds, and a testing temperature of 60° C. The same aggregate was used in all the specimens represented by each group of curves, the bitumen being varied as indicated.

Several indications of the test are evident from the chart (fig. 2). The test appears to differentiate clearly between mixtures varying in bitumen and dust content. It is very sensitive to slight variations in the density of well-compacted specimens. It is also apparent that a series rather than a single test is required to define the characteristics of any mixture. The failure of certain specimens to check with the average of their respective groups may be due to lack of uniformity in their densities or to certain other conditions of testing or molding which are as yet not clearly understood.

Considerable thought has been given to the method of interpreting curves of this nature. It is evident that data in this form are of little practical value without a knowledge of the degree of density to which mixtures may be compressed in service. Comparatively little information is available, but a study is being attempted which it is hoped will shed light on the matter. As a step in that direction, dry-aggregate voids tests are being made on the aggregates extracted from samples of pavements of different ages, and the results of these tests are compared with the computed voids of the aggregate as it exists in the original sample. Insufficient work has been done to warrant definite conclusions, but from the tests which have been made it is indicated that the voids existing in an aggregate may afford a measure of the compressibility of the aggregate when combined with bitumen.

As a tentative method of comparison between mixtures, the curves of Figure 2 are extended to the point of maximum possible compression indicated by the voids tests upon the aggregates. Unfortunately, these series do not include enough tests to define the slope of some of these curves as well as might be desired, but it seems that with percentages of bitumen which are less than sufficient to fill the voids in the aggregate, a compression can be attained which is, as a rule, within 1 per cent of the computed maximum possible density.

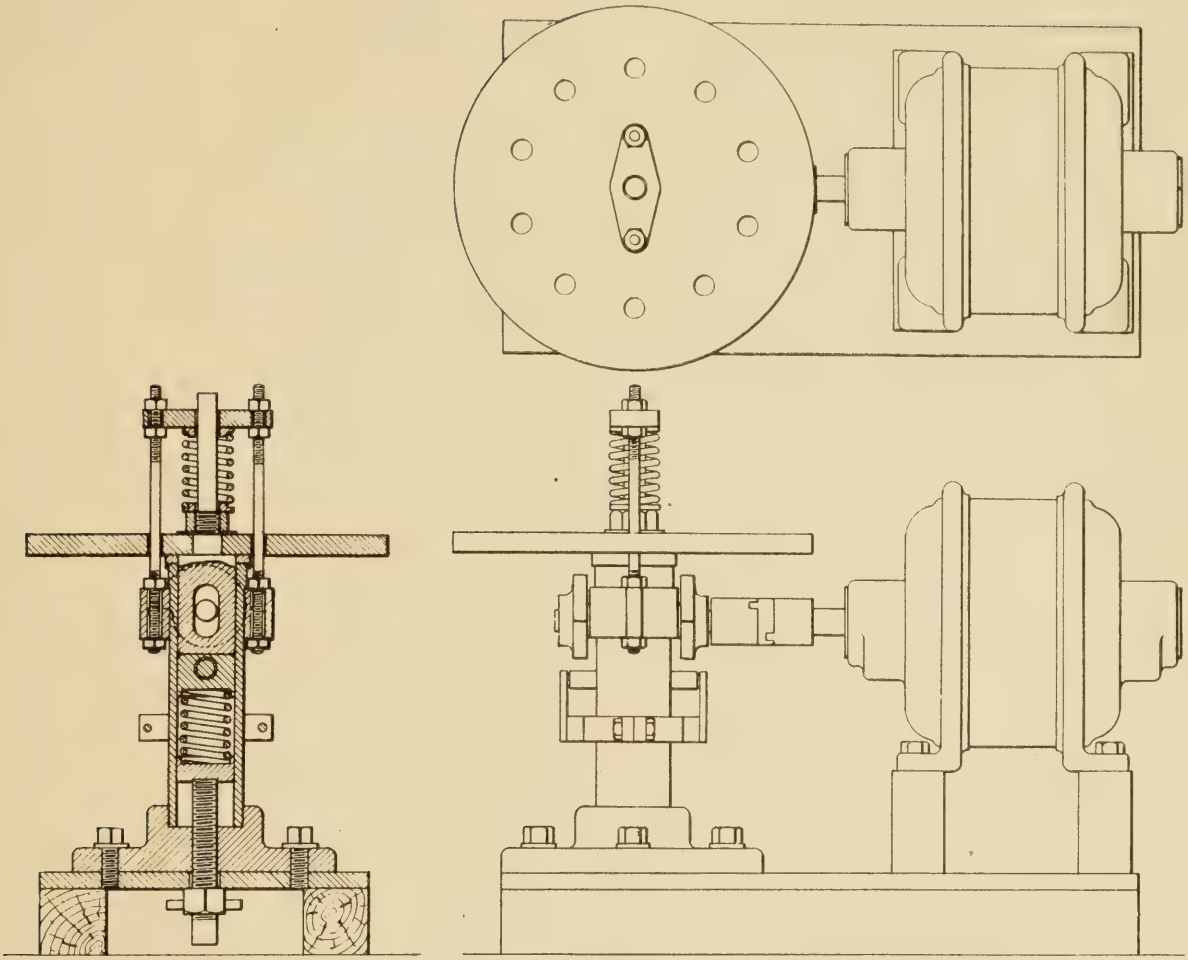

Fig. 3.—Apparatus Used in the Determination of Voids

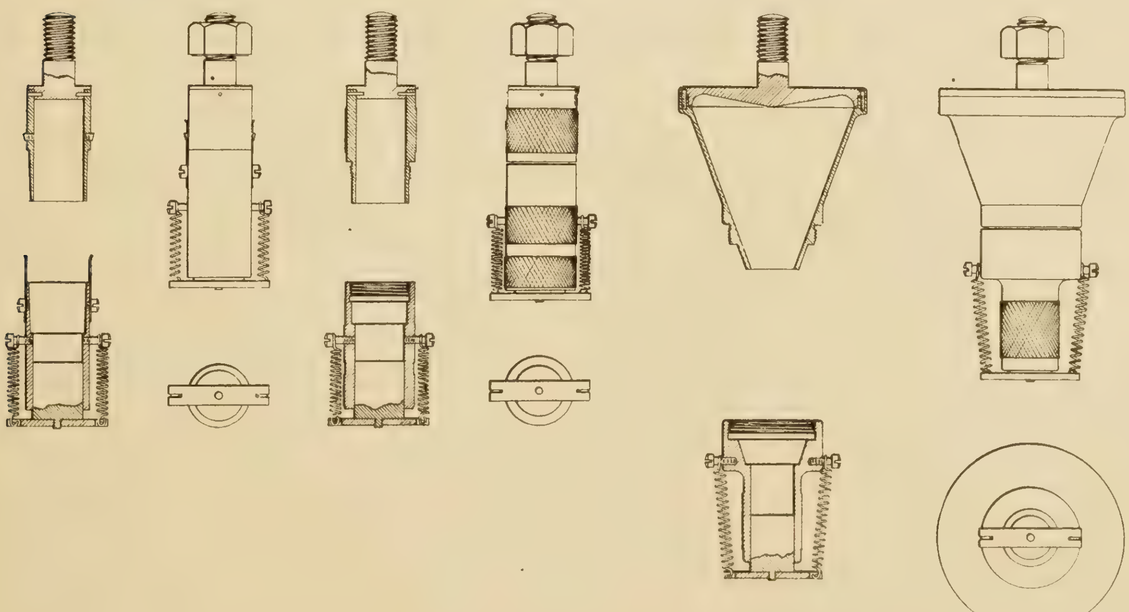

Fig. 4.—Containers Used in Apparatus for Void Determination

VOID DETERMINATOR

Another device developed by the Bureau of Public Roads is a mechanical means for compacting fine-aggregate mixtures in the test for voids. This apparatus is shown in Figure 3. A steel disk, 11 inches in diameter and $\frac{11}{16}$ inch thick, carries the aggregate containers and is vibrated rapidly between the lower and upper springs. Two cams driven by the motor are attached to the shaft, passing through the central column of the machine, alternately compressing and releasing the lower spring at the rate of about 1,500 times per minute. The throw of the disk is adjustable up to a maximum of 0.04 inch.

Figure 4 illustrates the types of containers which have been used to hold the aggregate being tested. The disk of the vibrator is perforated with ten ⅝-inch holes equally spaced on a circle concentric with its circumference. The bases of the containers are equipped with threaded rods by means of which they are bolted to the machine. Either cylindrical or conical containers may be used; and each container is fitted with a removable sleeve which may be attached to it by spring clips or by threads. At the beginning of the voids test, the sleeve is attached, slightly more aggregate than is necessary to fill the calibrated container is introduced, a rubber-shod cylindrical metal plunger is placed over the aggregate, and the whole apparatus is bolted to the vibrator. A 20-minute period of vibration has thus far been employed although it is likely that a somewhat shorter time may be sufficient to produce thorough compaction.

Considerable trouble has been experienced in obtaining a design for the containers which would resist the severe use to which they are subjected. The screw-thread type has virtually been discarded since it was found all but impossible to prevent dust from seeping into and ruining the threads of the containers. The spring-clip type seems to be more durable but as the holes in the clips wear larger it has been found necessary to take up the looseness which develops by wrapping and compressing a rubber band between the shoulder of the container and the sleeve.

Cylinders should be made by boring a solid steel rod in order to insure the greatest rigidity. Certain of the cylinders originally made have lately given erratic results and this has been traced to a very slight looseness which developed between the bases and the walls which, in this case, were turned out separately and assembled.

Most of the work has been done with cylinders 1 inch in diameter and of approximately 26 cubic centimeter capacity. Determinations by the method of hand tamping have been made concurrently with the machine test, using containers of identical construction for both purposes. Voids have also been calculated as they exist in 2-inch diameter cylindrical specimens of sheet asphalt mixtures compressed by the method devised by Hubbard and Field. The aggregates of these specimens were combined with percentages of bitumen from 7 to 14 per cent.

On the basis of the work done thus far it is believed that in the very near future the vibration method may be developed to give at least as complete compaction as can be obtained by either the more laborious hand method or by the method of direct compression under a predetermined load.

(Continued from page 201)

productive operation time worth 20 times that expenditure, then the needed attention to surface drainage will be readily forthcoming. Similarly, if proper attention to the maintenance of the road over which the hauling is done can be shown to yield certain profits above its cost, then such maintenance will become a regular part of the hauling plan. On one point, the data obtained are probably conclusive and that is that under anything like identical conditions the time lost will vary inversely with the ability of the management.

(Continued from p. 204)

slabs 6 feet long and 2 feet wide and 6 inches thick which were cast on the subgrade at the end of a number of the long pavement sections.

A few of the results obtained are given in Figure 4. The resistance is seen to be larger on a medium wet than on a dry subgrade. Tar paper is seen to have greatly reduced the resistance. A large reduction was found to occur also when the slab was moved short distances at 10-minute intervals instead of continuously over longer distances. Partial return of the slab after release of the force is found to take place.

The subgrade material on which these tests were made was a silty loam with very little clay, an exceptionally good material. In view of the favorable conditions under which these high results were obtained, it would seem that the generally accepted subgrade resistance coefficient of 2 might be too small for the average condition.

CURLING OF THE CONCRETE SLAB

The amount of curling of several different slabs has been measured over 24-hour periods. The method employed was to drive stakes along the slab at 2-foot intervals, and on these to mount dials which measured the vertical motion of the slab in thousandths of an inch. In Figure 5 the maximum curling is plotted for several periods of 24 hours. From these curves it can be seen that the maximum movement occurs at the end of the slab; that the maximum bending moment occurs from 6 to 8 feet from the end, and that the curling of the slab is restrained as the distance from the end is increased.

The curling curves shown indicate that a fiber stress of at least 100 pounds per square inch is possible; and it is evident that secondary transverse cracking may occur from this cause before the concrete has attained high strength.

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

ANNUAL REPORT

Report of the Chief of the Bureau of Public Roads, 1924.
Report of the Chief of the Bureau of Public Roads, 1925.
Report of the Chief of the Bureau of Public Roads, 1926.

DEPARTMENT BULLETINS

No. 105D. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913.
*136D. Highway Bonds. 20c.
220D. Road Models.
257D. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
*314D. Methods for the Examination of Bituminous Road Materials. 10c.
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*370D. The Results of Physical Tests of Road-Building Rock. 15c.
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390D. Public Road Mileage and Revenues in the United States, 1914. A Summary.
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1279D. Rural Highway Mileage, Income and Expenditures, 1921 and 1922.

DEPARTMENT CIRCULARS

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331C. Standard Specifications for Corrugated Metal Pipe Culverts.

MISCELLANEOUS CIRCULARS

No. 60M. Federal Legislation Providing for Federal Aid in Highway Construction.
*62M. Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal Aid Highway Projects. 5c.

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OFFICE OF THE SECRETARY CIRCULARS

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59. Automobile Registrations, Licenses, and Revenues in the United States, 1915.
63. State Highway Mileage and Expenditures to January 1, 1916.
*72. Width of Wagon Tires Recommended for Loads of Varying Magnitude on Earth and Gravel Roads. 5c.
73. Automobile Registrations, Licenses, and Revenues in the United States, 1916.
161. Rules and Regulations of the Secretary of Agriculture for Carrying Out the Federal Highway Act and Amendments Thereto.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

Vol. 5, No. 17, D- 2. Effect of Controllable Variables upon the Penetration Test for Asphalts and Asphalt Cements.
Vol. 5, No. 19, D- 3. Relation between Properties of Hardness and Toughness of Road-Building Rock.
Vol. 5, No. 20, D- 4. Apparatus for Measuring the Wear of Concrete Roads.
Vol. 5, No. 24, D- 6. A New Penetration Needle for Use in Testing Bituminous Materials.
Vol. 10, No. 5, D-12. Influence of Grading on the Value of Fine Aggregate Used in Portland Cement Concrete Road Construction.
Vol. 10, No. 7, D-13. Toughness of Bituminous Aggregates.
Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

* Department supply exhausted.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

STATUS OF FEDERAL AID HIGHWAY CONSTRUCTION

AS OF

NOVEMBER 30, 1926

STATES	FISCAL YEARS 1917-1926			FISCAL YEAR 1927									BALANCE OF FEDERAL AID FUND AVAILABLE FOR NEW PROJECTS	STATES
	PROJECTS COMPLETED PRIOR TO JULY 1, 1926			PROJECTS COMPLETED SINCE JUNE 30, 1926			*PROJECTS UNDER CONSTRUCTION			PROJECTS APPROVED FOR CONSTRUCTION				
	TOTAL COST	FEDERAL AID	MILES	TOTAL COST	FEDERAL AID	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES		
Alabama	$ 18,226,411.34	$ 8,725,985.09	1298.3	$ 1,334,428.79	$ 639,665.69	100.5	$ 5,802,525.54	$ 2,744,634.98	270.0	$ 141,817.86	$ 70,908.93	13.4	$ 2,168,260.31	Alabama
Arizona	10,949,878.25	5,963,772.35	729.8	272,263.37	172,004.74	26.7	1,589,950.50	1,097,546.15	85.0				2,483,925.76	Arizona
Arkansas	18,364,544.50	7,666,698.35	1323.0	925,556.13	452,766.52	74.3	4,213,879.04	1,991,172.27	272.9	1,490,889.48	741,335.08	94.3	753,831.78	Arkansas
California	27,142,696.90	13,003,592.30	1058.0	2,962,808.88	1,471,835.86	105.7	10,427,854.84	5,131,922.51	245.2	335,905.59	127,564.21	7.1	2,337,900.12	California
Colorado	13,905,904.64	7,127,288.18	745.0	886,679.90	492,409.14	32.7	5,602,303.77	2,716,073.46	258.8	538,721.78	299,416.03	30.2	1,700,625.19	Colorado
Connecticut	5,414,567.19	2,100,585.80	117.1	415,786.78	153,899.62	8.0	5,753,293.84	1,585,525.34	73.0	244,272.86	86,791.17	3.1	406,879.07	Connecticut
Delaware	4,918,052.29	1,781,665.60	124.3	741,382.64	306,931.14	17.6	915,210.80	373,034.05	25.4				12,427.21	Delaware
Florida	3,832,680.26	1,924,362.32	132.9	2,111,145.69	1,049,833.65	62.6	8,874,502.91	4,028,953.64	227.3	174,536.75	28,095.00	1.9	1,153,709.39	Florida
Georgia	24,791,206.97	11,664,237.86	1794.0	2,416,050.95	1,183,209.73	165.5	11,267,713.99	5,531,487.59	496.3	31,696.14	15,848.05	7.6	37,169.77	Georgia
Idaho	11,061,198.14	5,882,112.70	724.7	1,318,271.26	719,535.29	62.2	2,378,116.51	1,473,377.82	173.0	469,569.16	272,439.27	39.3	212,161.92	Idaho
Illinois	44,116,611.86	20,619,995.74	1377.7	2,012,307.84	980,960.66	68.1	9,556,175.20	4,639,573.48	345.7	1,004,521.91	432,782.21	32.5	3,158,985.91	Illinois
Indiana	16,949,425.97	8,172,125.19	534.3	2,408,698.84	1,135,591.51	71.0	17,470,671.26	8,223,878.57	502.5				672,759.63	Indiana
Iowa	29,062,375.40	11,926,302.10	2114.8	2,969,964.22	1,367,487.09	200.7	12,115,920.08	5,373,707.20	632.5	1,890,781.44	547,338.35	74.7	270,728.26	Iowa
Kansas	32,826,601.64	12,590,489.25	1160.6	522,940.32	235,898.35	48.9	14,211,641.66	5,580,237.15	781.6	2,533,013.33	838,968.54	113.0	218,817.71	Kansas
Kentucky	20,737,706.10	8,492,082.26	758.3	847,024.03	297,523.46	13.3	7,545,748.09	3,586,433.98	383.2	1,326,319.76	656,264.63	62.6	180,504.58	Kentucky
Louisiana	13,830,592.68	6,144,739.99	1056.9	871,444.84	387,478.39	31.8	3,606,456.02	1,734,604.66	185.1	1,382,376.53	640,869.93	42.1	364,715.03	Louisiana
Maine	8,747,552.76	4,192,507.39	303.6	547,274.10	228,564.49	19.1	2,580,964.80	912,095.53	70.7	1,084,926.14	402,821.22	33.2	728,839.37	Maine
Maryland	10,924,943.10	5,112,991.22	423.3	171,244.62	85,622.31	14.8	1,584,527.56	716,072.29	73.6				10,371.18	Maryland
Massachusetts	18,353,757.71	6,657,260.62	374.5	412,120.06	121,949.75	5.1	4,865,620.35	1,319,576.75	68.6	920,117.54	232,778.17	14.2	1,777,160.71	Massachusetts
Michigan	25,997,240.78	11,827,052.30	963.0	390,946.77	188,717.04	13.6	14,446,828.78	6,557,259.62	413.2	626,157.00	274,496.50	15.6	1,494,839.54	Michigan
Minnesota	37,170,985.95	15,586,116.56	3181.9	4,812,207.41	2,099,429.11	365.2	5,646,437.58	1,823,600.00	270.5	2,319,448.38	41,000.00	108.6	41,634.33	Minnesota
Mississippi	15,146,088.52	7,414,534.10	1129.0	1,131,550.92	563,148.80	71.7	7,596,137.22	3,698,750.24	377.7	317,835.24	158,917.61	34.9	292,667.26	Mississippi
Missouri	28,989,166.92	13,736,014.85	1543.2	6,125,841.88	2,678,728.20	188.6	15,245,401.71	6,060,545.97	408.6	342,099.68	143,422.14	5.0	167,724.84	Missouri
Montana	11,400,983.91	6,333,465.99	1054.9	858,208.82	509,109.72	59.1	2,039,801.08	1,732,168.93	172.2	817,555.73	429,967.89	87.3	4,420,172.67	Montana
Nebraska	11,533,401.62	5,474,202.52	1768.3	1,669,952.27	823,757.27	183.0	13,281,983.37	6,486,759.49	1392.0	521,763.45	248,964.84	55.5	1,601,551.98	Nebraska
Nevada	7,558,195.51	5,130,934.59	538.9	1,909,262.91	1,575,015.07	183.2	2,065,653.91	1,764,770.48	239.9				324,494.96	Nevada
New Hampshire	4,992,558.60	2,377,450.07	237.6				1,553,131.16	705,246.06	45.0				86,795.97	New Hampshire
New Jersey	16,346,301.01	5,099,342.21	290.3	1,574,934.83	308,980.29	18.1	7,931,185.48	2,726,328.56	47.2	1,092,069.63	223,605.00	14.9	110,163.94	New Jersey
New Mexico	12,404,337.77	7,339,657.38	1427.0	12,941.78	8,115.76	0.1	2,935,184.15	1,994,922.97	249.9	302,965.70	185,582.18	9.9	1,444,107.81	New Mexico
New York	43,224,279.79	17,911,957.19	1197.0	2,501,509.66	934,544.47	58.1	37,307,973.00	9,808,282.70	620.8	8,070,300.00	1,865,647.50	103.3	3,524,763.14	New York
North Carolina	27,009,419.47	11,177,337.94	1257.9	4,852,692.24	1,923,238.17	102.8	4,786,044.21	2,206,892.72	143.6	876,813.00	408,442.59	34.4	1,294.58	North Carolina
North Dakota	12,313,311.40	6,031,959.78	2193.1	1,833,749.14	881,287.93	222.4	6,480,799.44	3,438,174.18	938.4	513,983.76	256,941.82	79.1	140,395.29	North Dakota
Ohio	47,699,532.90	17,371,787.03	1364.1	2,541,449.91	1,064,321.47	94.1	13,100,141.20	4,972,202.19	381.4	1,399,989.92	561,020.00	17.9	1,762,465.31	Ohio
Oklahoma	28,247,950.33	13,159,999.15	1178.9	900,671.53	439,056.35	41.7	2,650,852.43	1,104,032.58	102.0	2,397,066.86	956,990.24	146.5	399,708.68	Oklahoma
Oregon	17,027,978.42	8,593,214.79	939.2	702,784.65	403,640.92	23.7	3,250,886.94	1,774,756.86	128.0	293,328.42	6,000.00	7.0	101,734.43	Oregon
Pennsylvania	61,366,150.80	21,560,732.04	1188.8	250,508.96	47,988.62	3.2	29,958,176.82	8,526,177.50	597.2	2,659,544.04	917,194.42	59.0	286,788.42	Pennsylvania
Rhode Island	3,988,616.09	1,558,829.06	86.7	274,781.19	113,520.00	7.6	1,245,917.75	326,130.00	21.8	917,282.21	250,155.00	16.6	418,934.94	Rhode Island
South Carolina	15,020,639.90	6,766,322.93	1491.9	1,158,643.57	454,194.28	58.0	5,712,030.93	2,491,292.35	194.5	99,046.24	42,921.58	10.3	46,792.86	South Carolina
South Dakota	17,468,373.19	8,603,926.97	2181.2	1,045,179.92	517,228.44	177.9	3,706,472.30	1,978,341.39	643.0	113,029.83	30,539.05	13.0	136,854.15	South Dakota
Tennessee	21,624,631.57	10,276,584.02	780.0	1,199,774.63	567,186.82	44.4	8,603,458.25	3,817,387.29	236.0	1,153,562.01	320,518.04	35.0	298,914.83	Tennessee
Texas	69,183,673.48	27,440,254.72	4920.2	3,690,005.31	1,660,238.48	247.3	17,061,436.34	7,572,699.59	721.1	3,893,068.19	1,884,190.93	126.9	2,049,047.28	Texas
Utah	8,253,178.03	5,098,440.68	546.4	393,597.51	293,480.96	29.4	1,794,506.96	1,354,767.12	166.0	789,883.79	502,111.44	44.9	569,978.80	Utah
Vermont	4,242,042.64	2,017,699.51	134.5	81,136.58	38,579.83	2.0	2,218,938.48	860,003.59	41.1				352,224.07	Vermont
Virginia	21,990,249.44	10,385,728.11	1005.5	1,208,600.77	538,360.39	39.8	5,924,449.90	2,539,832.71	165.9	530,067.63	28,640.23	11.1	8,952.56	Virginia
Washington	17,078,511.63	7,782,909.46	668.6	300,577.74	116,642.49	8.7	4,382,234.09	2,045,600.00	94.9	91,208.37	26,000.00	4.6	174,624.05	Washington
West Virginia	9,473,716.44	4,141,062.65	392.9	457,126.16	193,696.41	12.4	6,125,251.18	2,446,968.32	178.7	1,394,581.91	474,962.60	78.8	95,821.02	West Virginia
Wisconsin	24,656,508.19	10,292,705.73	1592.1	101,729.42	50,664.71	9.3	8,880,219.19	4,243,708.88	395.2	120,766.17	60,382.00	4.6	2,691,353.68	Wisconsin
Wyoming	10,928,202.56	6,040,887.05	1133.5	739,672.78	471,486.00	85.3	2,613,563.47	1,656,727.22	200.8	8,655.90	5,557.00		391,616.73	Wyoming
Hawaii				343,664.15	97,440.00	6.5	708,620.71	215,195.18	9.4				787,517.82	Hawaii
TOTALS	966,692,834.36	426,178,703.58	52,526.6	67,111,096.57	31,034,865.49	3,485.8	369,417,694.68	155,589,430.91	14,766.4	45,231,339.33	15,698,391.39	1,694.0	42,373,603.63	TOTALS

* Includes projects reported completed (final vouchers not yet paid) totaling: Estimated cost $117,332,109.99 Federal aid $ 50,879,199.26 Miles 4288.1